

AD-A121 686

ROLE OF AMINES IN ADHESION OF POLYBUTADIENE TO GLASS
SUBSTRATES IV THE EF. (U) AKRON UNIV OH INST OF POLYMER
SCIENCE Y ECKSTEIN ET AL. OCT 82 TR-25

171

UNCLASSIFIED

N00014-76-C-0408

F/G 9/1

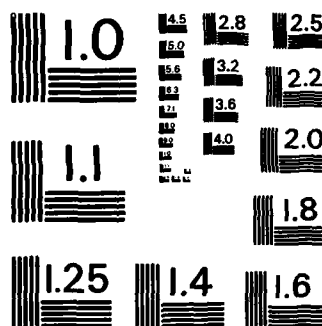
NL

END

FILMED

1

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD A121686

DTIC FILE COPY

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report No. 25	2. GOVT ACCESSION NO. AD-A121686	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Role of Amines in Adhesion of Polybutadiene to Glass Substrates. IV. The Effect of Amine Structure and Concentration on the Strength of Adhesion		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Y. Eckstein and P. Dreyfuss		8. CONTRACT OR GRANT NUMBER(s) N00014-76-C-0408
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute of Polymer Science The University of Akron Akron, Ohio 44325		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 092-555
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research, Power Program Arlington, VA 22217		12. REPORT DATE October, 1982
		13. NUMBER OF PAGES 20
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) According to attached distribution list. Approved for public release; distribution unrestricted		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Submitted to J. Adhesion		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) amine structure, amine concentration, adhesion, polybutadiene, glass		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An attempt to elucidate the role of amines in general, and of 3-amino-propyltriethoxysilane in particular, has been made through a study of the title subject by several different approaches. This paper describes the effect of amine structure and concentration on the strength of adhesion of peroxide cured polybutadiene to a glass surface. It demonstrates that adhesion of polybutadiene to glass surfaces is enhanced by incorporation of small amounts of amines into the elastomer. An 80-fold increase in the work		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 68 IS OBSOLETE
S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

82

1

19

0

DTIC
ELECTE
NOV 19 1982
S E

of adhesion was observed in the presence of 3-aminopropyltrimethoxysilane. The results are interpreted in terms of information reported in previous papers in this series.

OFFICE OF NAVAL RESEARCH

Contract N00014-76-C-0408

Project NR 092-555

Technical Report No. 25

ROLE OF AMINES IN ADHESION OF POLYBUTADIENE TO GLASS SUBSTRATES

IV. EFFECT OF AMINE STRUCTURE AND CONCENTRATION ON STRENGTH OF ADHESION

by

Y. Eckstein and P. Dreyfuss

Institute of Polymer Science
The University of Akron
Akron, Ohio 44325



Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

October, 1982

Reproduction in whole or in part is permitted for any purpose
of the United States Government.

Approved for Public Release; Distribution Unrestricted.

INTRODUCTION

In the course of our earlier studies of the adhesion of polybutadiene to inorganic crystalline substrates and of the physical properties of polybutadiene containing glass bead fillers treated with 3-aminopropyltriethoxysilane, an increase in adhesion was found when amines were present at the interface between the elastomer and the crystals (1) or glass beads (2). Similar observations have been reported in the literature (3-5). Also, in some experimental studies on the adhesion of polybutadiene to various substrates it was observed that amine antioxidants added to the elastomer compound had a profound effect in increasing the level of adhesion (6). The reasons for these increases are not at all apparent. These observations led us to undertake this study of the role of amines in the adhesion of polybutadiene to glass substrates. This paper describes the effect of amine structure and concentration on the strength of adhesion. The results are interpreted on the basis of information gained in earlier studies of model systems (7-9). In paper I of this series, reactions of amines during peroxide curing of polybutadiene were considered and the effects of the addition of very small concentrations of amines on mechanical properties of the cured polybutadiene were studied (7). In paper II of the series reactions of amines with trimethoxysilanol and/or fumed silica were studied by IR, NIR, GLC, ^{13}C NMR, ^1H NMR, MS and one product was characterized by elemental analysis (8). In paper III of the series the effects of amines on the reaction of dicumylperoxide with model olefins were examined (9). The first paper was published earlier and the principal conclusions are

summarized in paper II of the Series. Papers II and III precede this paper and the reader should refer to them for detailed bases of the conclusions from them used in the discussion of adhesion results below.

EXPERIMENTAL

Materials

Most of the materials used in this study have been described in previous papers in this series (7-9). Glass slides were pre-cleaned soda lime microscope slides from B. H. Sargent & Co.

Cleaning of Glass Slides

The glass slides were washed successively with boiling 2% "Microsolution" for 1 hr, distilled water, boiling 1% phosphoric acid for 1/2 hr., distilled water and boiling distilled water for 1/2 hr., before drying at 140°C for 2 hrs and storing in a dessicator over P_2O_5 .

Crosslinking of Polybutadiene (PB)

Amines were incorporated into PB as described in Part I of this series. For adhesion measurements, PB containing amine, was crosslinked with 0.1 phr of peroxide. Before bonding, the elastomer was pressed into a thin layer (~ 0.2 mm) by premolding for 1 hr at 65°C, then pressed into a sheet of cotton cloth and again premolded for 1 hr at 65°C. The cloth backed layer was then pressed against cleaned glass slides for 2 hrs at 149°C in a PHI press at pressure of ~ 6 psi/5" ram. The thickness of the elastomer interlayer in the resulting cloth-elastomer-glass sandwich was 0.2 mm.

Measurement of Work of Adhesion

180° Peeling tests were carried out on strips of cloth backed elastomer layer after trimming them to a uniform width on the glass of 2 cm. The elastomer layer was peeled off the glass at constant rate, 0.5 cm/min (0.0083 cm/sec). The work of adhesion per unit area of interface was calculated from the time average of the peel force P per unit width of the detaching layer: $W = 2P$.

RESULTS

The values of the work of adhesion of PB, blended with different amino compounds, to the glass surface are listed in Table I. The amines used for this part of the study included aniline(A), m-phenylenediamine(PDA), piperazine(P), 1,4-diaminobutane(AB), and 3-aminopropyltriethoxysilane(AS). The data for the work of adhesion of PB containing different concentrations of PDA or AS indicate clearly that the adhesion may be enhanced by increasing the concentration of the amine in the vulcanizate. Thus, for example, at a concentration of 0.5×10^{-4} mole of AS/100g PB, the work of adhesion increased by about 16 J/m² in comparison to peroxide cured PB in absence of the amine. When the concentration of AS was increased by a factor of 4, cohesive failure in the rubber phase was observed. Similar dependence of the work of adhesion on the concentration of PDA was observed; however, much higher concentrations of the amine were needed to produce an effect similar to that of AS. Curiously, when AS is added to the rubber at concentrations calculated to be equivalent to formation of a monolayer of silane on the glass surface (1.85×10^{-6} mole AS/100g PB) the work of adhesion

was not increased. This implies that only part of the AS reacts with the glass surface, while another part is consumed in a reaction with the polymeric phase. Alternatively, since the AS was blended into the rubber rather than applied to the glass surface directly, the inefficiency of the AS as a coupling agent may be caused by slow diffusion.

At equivalent molar concentrations of amine, the order of increase in the work of adhesion of PB to glass was:

$$PB = A < P < AB < PDA \ll AS$$

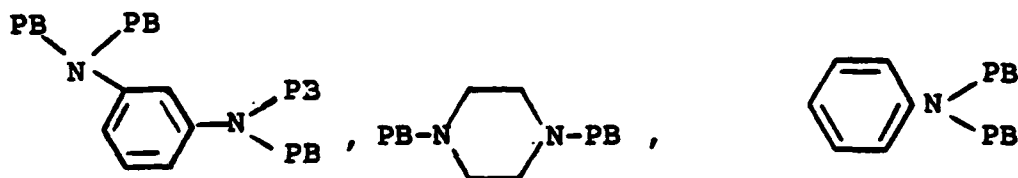
DISCUSSION

Measurements of the mechanical properties of peroxide cured PB in the presence of different amines (7) and studies of model reactions involving (i) amines and silanol groups (8), (ii) amines and peroxides in olefins (9) and (iii) amines, different kinds of double bonds in olefins, peroxides and silanol groups (9) provided information essential for understanding the role of amines in the adhesion of polybutadiene to glass. The studies indicated that the consideration of the mechanism by which amines can react in these systems can be divided for convenience into two parts; namely, reactions involving aromatic amines and piperazine and reactions involving aliphatic amines.

Aromatic Amines and Piperazine

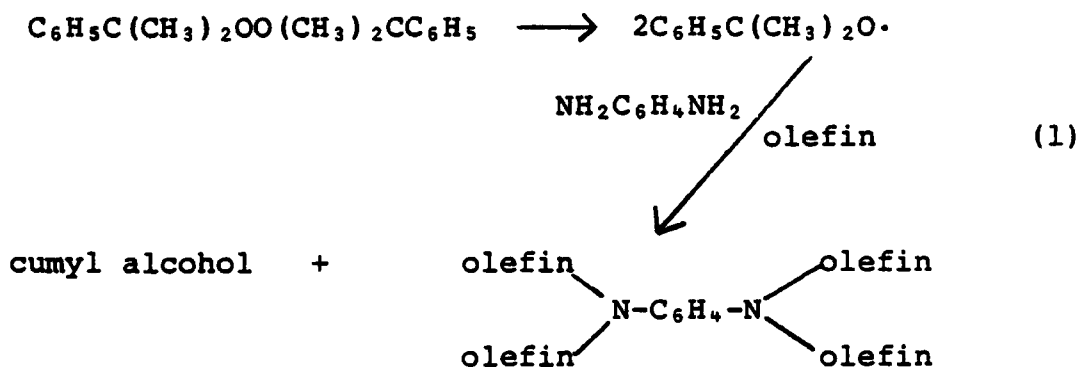
Measurements of mechanical properties (7) showed that tensile strength and crosslink density of peroxide cured PB are enhanced by the presence of aromatic amines and piperazine as long as the

concentration of amine is of the same order of magnitude as that of the peroxide. (At higher molar ratios of amine to peroxide, the amine serves as a radical trap.) The order of enhancement was $PDA > P > A \approx 0$, which is the same as the order of increase in the work of adhesion shown in Table I. The maximum enhancement occurred when the molar concentration of labile hydrogens of the amine was equal to the molar concentration of alkoxy radicals derived from the peroxide. We concluded on the basis of the results reported in previous papers (7-9) that the amines participate in the cross-linking reaction to form networks including structures of the following form:



Thus the diamines led to additional crosslinks and the primary diamine, PDA, linked four chains while the secondary diamine, P, linked two. With the diamines the rings become part of the crosslinks and reduce the flexibility of the chains in the region of the crosslinks. According to Pluddemann's hypothesis (10), increased crosslinking and increased rigidity of the interface are essential for good adhesion in a glass resin system. By the same reasoning the monamine, A, acting in the same way contributed little or nothing to either the tensile strength or the work of adhesion because it became part of the straight chain (7-9).

Studies of the effect of PDA on the reaction of dicumyl peroxide with the olefins 1-decene or 2-hexene supported the mechanism suggested (9). In both systems the amount of cumyl alcohol formed as a result of decomposition of the peroxide according to equation 1:

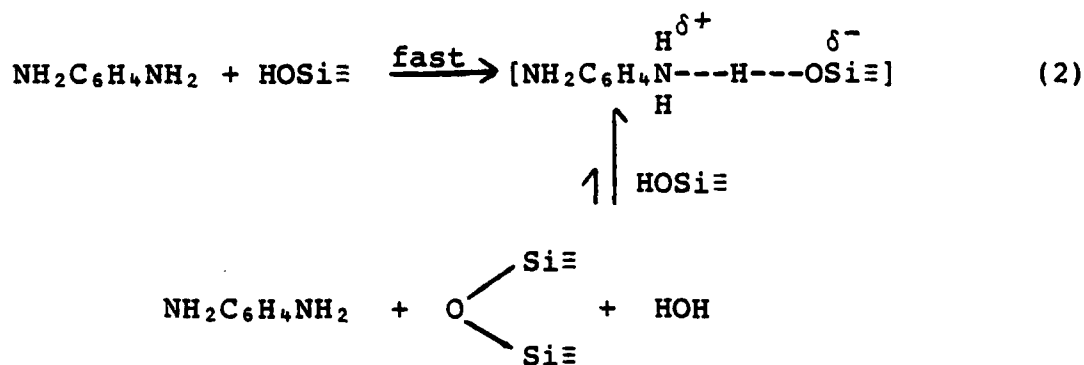


was four or more times higher than that observed in the reaction of the olefin alone with peroxide even though only 50% of the total concentration of amine and olefin were consumed. The concentration of cumyl alcohol was also twice as great as that formed in a comparable reaction between AS and dicumyl peroxide. Presumably all four hydrogens are available for abstraction by the cumyl radical. In our reaction mixtures the amine itself reacted with the olefin to give a second insoluble phase.

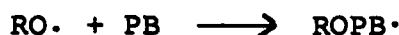
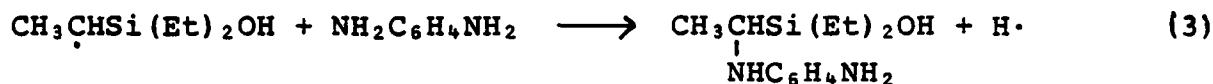
Supporting evidence for the cleavage of the N-H bond rather than the C-N bond of the amine is found in the work of Nazaki and Bartlett (11), who found that when benzoyl peroxide decomposes in amines, the products formed are characteristic of N-H scission. Additional evidence for the formation of C-N bonds comes from the work of Lewis and Correa (12), who reported that the photochemical

reaction of singlet 9-phenanthrenecarbonitrile with diethylamine in nonpolar solvents yields a diethylaminyl radical exclusively and the principal product formed is the addition product 9-(9-diethylamino-9,10-dihydro)phenanthrene carbonitrile. Thus the total evidence is strong that the amine becomes chemically bonded to the PB, a comparatively nonpolar medium.

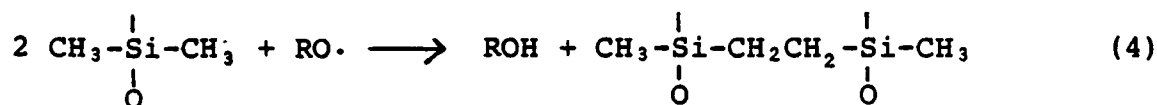
Bonding of the amine to the PB is not sufficient alone to account for the improved adhesion shown in Table I. The interactions between the amine and the -SiOH groups on the glass needs to be considered also. Model reactions between -SiOH groups on either Et_3SiOH or Cab-O-Sil (8) in the absence of peroxide showed that the PDA serves only as a catalyst for the condensation of the -SiOH groups and the concentration of PDA remains unchanged as shown in equation 2:



In the presence of peroxide, the concentration of amino groups decreased dramatically and the concentration of cumyl alcohol was lower by a factor of two (9). The second amine group appeared to react with the silanol to form a chemical bond as shown schematically in equation 3 for one ethyl group and one nitrogen on the amine:

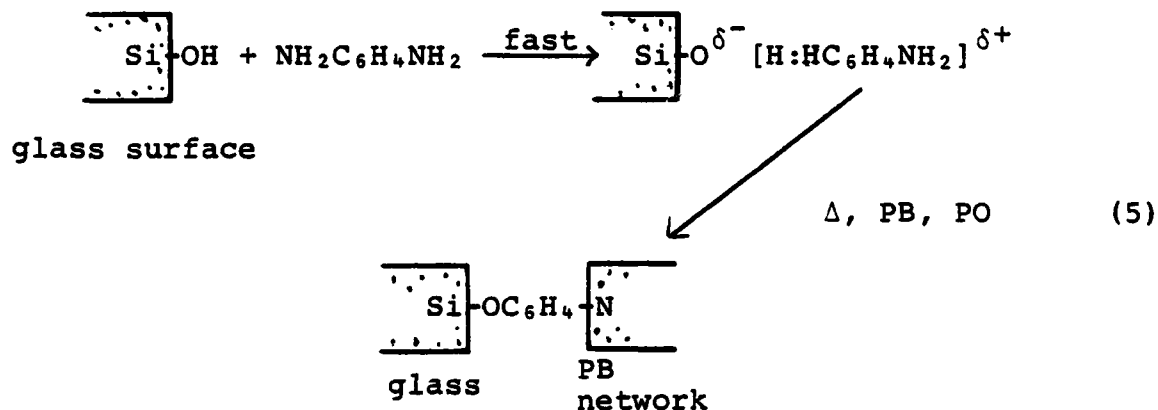


These reactions are analogous to the peroxide curing of polyorgano-silanes shown in equation 4 (13):



but instead of combination of alkyl radicals, trapping of the radical by the amine occurs.

Glass (Cab-O-Sil) does not have any alkyl groups. Model studies (8) have shown that the first reaction in the series of equations 5 occurs.



The ionic bonding alone can account for reducing the number of NH_2 groups available for reaction with the PB and peroxide. It can probably also account for the observed increase in the work of adhesion in the presence of PDA. Formation of a true covalent bond of the type shown in the second reaction might occur under curing conditions; however, we have no evidence that such scission takes place in our systems.

Aminosilanes and Acyclic Aliphatic Amines

The work of adhesion of PB to glass was increased almost twofold by the addition of AB, a diamine. The effect was about the same as that of PDA and the mechanism by which adhesion is improved is probably similar to that of PDA. In addition, model compound studies (8) showed that acyclic aliphatic amines in general have a marked tendency to form carbamates (carbon dioxide adducts of amines) and that carbamates enhance the reactivity of the aliphatic amines. This may account for the high reactivity of AB. Again model compound work reported in previous studies by others supports these conclusions (11, 14). The work of Nazaki and Bartlett (11) indicates reaction at the N-H bond rather than at the C-N bond.

Addition of AS to the PB had an outstanding effect on the work of adhesion of PB to glass. (See Table I). Added at much lower levels than any of the other amines in this study, AS nevertheless had by far the greatest effect at improving adhesion. At sufficiently high concentration, its addition resulted in cohesive failure in the PB. Since AS has only one amino group and that group is not very different from those already described, the difference must arise from the three ethoxy groups and their interaction with the glass surface and the PB.

Numerous studies indicate that, mechanistic considerations aside, ethoxysilanes can react with -SiOH groups to form chemical bonds and that further condensation of the ethoxy group leads to a polysiloxane coating on the glass (10, 15-18). The overall reactions are shown schematically in equation 6.

References

1. P. Dreyfuss and P. Marteny, unpublished results.
2. P. Dreyfuss, A. N. Gent and J. R. Williams, J. Polym. Sci.:Polym. Phys. Ed., 18, 2135 (1980).
3. M. W. Ranney and C. A. Pagano, Rubber Chem. Technol., 44, 1080 (1971).
4. M. W. Ranney, S. E. Berger and J. G. Marsden, Chapter 5 in "Composite Materials", 6, E. P. Plueddemann, Ed., Academic Press, N.Y., N.Y., 1974, p 131.
5. W. C. Smith and N. F. Neuman, Rubb. World, 74, 153 (1966).
6. A. N. Gent and S. S. Tremlin, unpublished results.
7. Y. Eckstein and P. Dreyfuss, J. Adhesion, 13, 303 (1982).
8. Y. Eckstein and P. Dreyfuss, "Role of Amines in Adhesion of Polybutadiene to Glass Substrates. II. Reactions of Amines with Triethylsilanol and/or Fumed Silica", "Technical Report No. 23 to ONR on Contract N00017-76-C-0408, October, 1982".
9. Y. Eckstein and P. Dreyfuss, "Role of Amines in Adhesion of Polybutadiene to Glass Substrates. III. Effect of Amines on the Reaction of Peroxide with Olefinic Groups", "Technical Report No. 24 to ONR on Contract N00014-76-C-0408, October, 1982.
10. E. P. Plueddemann, Chapter 6 in "Composite Materials", 6, E. P. Plueddemann, Ed., Academic Press, N.Y., N.Y., 1974, p. 173.
11. K. Nazaki and P. D. Bartlett, J. Am. Chem. Soc., 68, 1986 (1946).
12. F. D. Lewis and P. E. Correa, J. Am. Chem. Soc., 103, 7347 (1981).
13. W. Noll, "Chemistry and Technology of Silicones", Academic Press, N.Y., N.Y., 1968, p. 230.
14. S. Gambarjan, Ber., 58B, 1775 (1925).

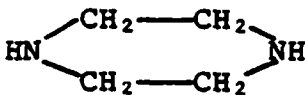
15. M. R. Rosen, J. of Coatings Technol., 50, 70 (1978).
16. R. L. Kaas and J. L. Kardos, Polym. Eng. and Science, 11, 11 (1971).
17. K. Grohmann, Ph.D. Thesis, University of Houston, 1972.
18. W. Parr and K. Grohmann, Tetrahedron Lett., 28, 2633 (1971).

Acknowledgement

This work forms part of a program of research on the adhesion of elastomers supported by a research grant from the Office of Naval Research. The authors thank the Firestone Tire and Rubber Co. for supplying the sample of Diene 35NFA and Hercules, Inc. for a sample of dry dicumyl peroxide, Di-Cup[®] R.

13 .
TABLE I

Work of Adhesion of Peroxide Cured PB to a Glass Surface in
The Presence of Amines

Amine ^a	Structure	Amine concentration x10 ⁴ mole/100g PB	W _a (J/m ²)	$\frac{W_A^{\text{Amine}^b}}{W_A^{\text{PB}}}$
-	-	-	6.2	1.0
A	C ₆ H ₅ NH ₂	4.0	6.2	1.0
PDA	1,3-C ₆ H ₄ (NH ₂) ₂	2.0	8.6	1.4
PDA	"	3.8	13.0	2.1
P		4.0	7.9	1.3
AB	(NH ₂ CH ₂ CH ₂) ₂	4.0	11.0	1.8
AS	(EtO) ₃ Si(CH ₂)NH ₂	0.0185	6.2	0
AS	"	0.46	22.3	3.6
AS	"	2.0	490.0 ^c	79.0
S	Et ₃ SiOH	3.9	6.1	1.0

^aA = aniline, PDA = m-phenylenediamine, P = piperazine,
AB = 1,4-diaminobutane, AS = 3-aminopropyltriethoxysilane,
S = triethylsilanol

^b $\frac{W_A^{\text{amine}}}{W_A^{\text{PB}}}$ = work of adhesion with added amine/work of adhesion
without added amine

^cCohesive failure in the PB phase was observed

DISTRIBUTION LIST

	<u>No. Copies</u>		<u>No. Copies</u>
Dr. L.V. Schmidt Assistant Secretary of the Navy (R,E, and S) Room SE 731 Pentagon Washington, D.C. 20350	1	Dr. F. Roberto Code AFRPL MKPA Edwards AFB, CA 93523	1
Dr. A.L. Slafkosky Scientific Advisor Commandant of the Marine Corps Code RD-1 Washington, D.C. 20380	1	Dr. L.H. Caveny Air Force Office of Scientific Research Directorate of Aerospace Sciences Bolling Air Force Base Washington, D.C. 20332	1
Dr. Richard S. Miller Office of Naval Research Code 413 Arlington, VA 22217	10	Mr. Donald L. Ball Air Force Office of Scientific Research Directorate of Chemical Sciences Bolling Air Force Base Washington, D.C. 20332	1
Mr. David Siegel Office of Naval Research Code 260 Arlington, VA 22217	1	Dr. John S. Wilkes, Jr. FJSRL/NC USAF Academy, CO 80840	1
Dr. R.J. Marcus Office of Naval Research Western Office 1030 East Green Street Pasadena, CA 91106	1	Dr. R.L. Lou Aerojet Strategic Propulsion Co. P.O. Box 15699C Sacramento, CA 95813	1
Dr. Larry Peebles Office of Naval Research East Central Regional Office 666 Summer Street, Bldg. 114-D Boston, MA 02210	1	Dr. V.J. Keenan Anal-Syn Lab Inc. P.O. Box 547 Paoli, PA 19301	1
Dr. Phillip A. Miller Office of Naval Research San Francisco Area Office One Hallidie Plaza, Suite 601 San Francisco, CA 94102	1	Dr. Philip Howe Army Ballistic Research Labs ARRADCOM Code DRDAR-BLT Aberdeen Proving Ground, MD 21005	1
Mr. Otto K. Heiney AFATL - DLDL Elgin AFB, FL 32542	1	Mr. L.A. Watermeier Army Ballistic Research Labs ARRADCOM Code DRDAR-BLI Aberdeen Proving Ground, MD 21005	1
Mr. R. Geisler ATTN: MKP/MS24 AFRPL Edwards AFB, CA 93523	1	Dr. W.W. Wharton Attn: DASMZ-RKL Commander U.S. Army Missile Command Redstone Arsenal, AL 35898	1

DISTRIBUTION LIST

	<u>No. Copies</u>		<u>No. Copies</u>
Dr. R.G. Rhoades Commander Army Missile Command DRSMI-R Redstone Arsenal, AL 35898	1	Dr. E.H. Debutts Hercules Inc. Baccus Works P.O. Box 98 Magna, UT 84044	1
Dr. W.D. Stephens Atlantic Research Corp. Pine Ridge Plant 7511 Wellington Rd. Gainesville, VA 22065	1	Dr. James H. Thacher Hercules Inc. Magna Baccus Works P.O. Box 98 Magna, UT 84044	1
Dr. A.W. Barrows Ballistic Research Laboratory USA ARRADCOM ORDAR-BLP Aberdeen Proving Ground, MD 21005	1	Mr. Theodore M. Gilliland Johns Hopkins University APL Chemical Propulsion Info. Agency Johns Hopkins Road Laurel, MD 20810	1
Dr. C.M. Frey Chemical Systems Division P.O. Box 358 Sunnyvale, CA 94086	1	Dr. R. McGuire Lawrence Livermore Laboratory University of California Code L-324 Livermore, CA 94550	1
Professor F. Rodriguez Cornell University School of Chemical Engineering Olin Hall, Ithaca, N.Y. 14853	1	Dr. Jack Linsk Lockheed Missiles & Space Co. P.O. Box 504 Code Org. 83-10, Bldg. 154 Sunnyvale, CA 94088	1
Defense Technical Information Center DTIC-DDA-2 Cameron Station Alexandria, VA 22314	12	Dr. B.G. Craig Los Alamos National Lab P.O. Box 1663 NSP/DOD, MS-245 Los Alamos, NM 87545	1
Dr. Rocco C. Musso Hercules Aerospace Division Hercules Incorporated Alleghany Ballistic Lab P.O. Box 210 Washington, D.C. 21502	1	Dr. R.L. Rabie WX-2, MS-952 Los Alamos National Lab. P.O. Box 1663 Los Alamos NM 37545	1
Dr. Ronald L. Simmons Hercules Inc. Eglin AFATL/DLOL Eglin AFB, FL 32542	1	Dr. R. Rogers Los Alamos Scientific Lab. P.O. Box 1663 Los Alamos, NM 87545	1

DISTRIBUTION LIST

	<u>No. Copies</u>		<u>No. Copies</u>
Mr. R. Brown Naval Air Systems Command Code 330 Washington, D.C. 20361	1	Dr. J. Schnur Naval Research Lab. Code 6510 Washington, D.C. 20375	1
Dr. H. Rosenwasser Naval Air Systems Command AIR-310C Washington, D.C. 20360	1	Mr. R. Beauregard Naval Sea Systems Command SEA 64E Washington, D.C. 20362	1
Mr. B. Sobers Naval Air Systems Command Code 03P25 Washington, D.C. 20360	1	Mr. G. Edwards Naval Sea Systems Command Code 62R3 Washington, D.C. 20362	1
Dr. L.R. Rothstein Assistant Director Naval Explosives Dev. Engineering Dept. Naval Weapons Station Yorktown, VA 23691	1	Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, PA 19112	1
Dr. Lionel Dickinson Naval Explosive Ordnance Disposal Tech. Center Code D Indian Head, MD 20640	1	Dr. H.G. Adolph Naval Surface Weapons Center Code R11 White Oak Silver Spring, MD 20910	1
Mr. C.L. Adams Naval Ordnance Station Code PM4 Indian Head, MD 20640	1	Dr. T.D. Austin Naval Surface Weapons Center Code R16 Indian Head, MD 20640	1
Mr. S. Mitchell Naval Ordnance Station Code 5253 Indian Head, MD 20640	1	Dr. T. Hall Code R-11 Naval Surface Weapons Center White Oak Laboratory Silver Spring, MD 20910	1
Dr. William Tolles Dean of Research Naval Postgraduate School Monterey, CA 93940	1	Mr. G.L. Mackenzie Naval Surface Weapons Center Code R101 Indian Head, MD 20640	1
Naval Research Lab. Code 6100 Washington, D.C. 20375	1	Dr. K.F. Mueller Naval Surface Weapons Center Code R11 White Oak Silver Spring, MD 20910	1

DISTRIBUTION LIST

	<u>No. Copies</u>		<u>No. Copies</u>
Mr. J. Murrin Naval Sea Systems Command Code 62R2 Washington, D.C. 20362	1	Dr. A. Nielsen Naval Weapons Center Code 385 China Lake, CA 93555	1
Dr. D.J. Pastine Naval Surface Weapons Center Code R04 White Oak Silver Spring, MD 20910	1	Dr. R. Reed, Jr. Naval Weapons Center Code 388 China Lake, CA 93555	1
Mr. L. Roslund Naval Surface Weapons Center Code R122 White Oak, Silver Spring MD 20910	1	Dr. L. Smith Naval Weapons Center Code 3205 China Lake, CA 93555	1
Mr. M. Stosz Naval Surface Weapons Center Code R121 White Oak Silver Spring, MD 20910	1	Dr. B. Douda Naval Weapons Support Center Code 5042 Crane, Indiana 47522	1
Dr. E. Zimmet Naval Surface Weapons Center Code R13 White Oak Silver Spring, MD 20910	1	Dr. A. Faulstich Chief of Naval Technology MAT Code 0716 Washington, D.C. 20360	1
Dr. D. R. Derr Naval Weapons Center Code 388 China Lake, CA 93555	1	LCDR J. Walker Chief of Naval Material Office of Naval Technology MAT, Code 0712 Washington, D.C. 20360	1
Mr. Lee N. Gilbert Naval Weapons Center Code 3205 China Lake, CA 93555	1	Mr. Joe McCartney Naval Ocean Systems Center San Diego, CA 92152	1
Dr. E. Martin Naval Weapons Center Code 3858 China Lake, CA 93555	1	Dr. S. Yamamoto Marine Sciences Division Naval Ocean Systems Center San Diego, CA 91232	1
Mr. R. McCarten Naval Weapons Center Code 3272 China Lake, CA 93555	1	Dr. G. Bosmajian Applied Chemistry Division Naval Ship Research & Development Center Annapolis, MD 21401	1
		Dr. H. Shuey Rohn and Haas Company Huntsville, Alabama 35801	1

DISTRIBUTION LIST

	<u>No. Copies</u>		<u>No. Copies</u>
Dr. J.F. Kincaid Strategic Systems Project Office Department of the Navy Room 901 Washington, D.C. 20375	1	Dr. C.W. Vriesen Thiokol Elkton Division P.O. Box 241 Elkton, MD 21921	1
Strategic Systems Project Office Propulsion Unit Code SP2731 Department of the Navy Washington, D.C. 20376	1	Dr. J.C. Hinshaw Thiokol Wasatch Division P.O. Box 524 Brigham City, Utah 83402	1
Mr. E.L. Throckmorton Strategic Systems Project Office Department of the Navy Room 1043 Washington, D.C. 20376	1	U.S. Army Research Office Chemical & Biological Sciences Division P.O. Box 12211 Research Triangle Park NC 27709	1
Dr. D.A. Flanigan Thiokol Huntsville Division Huntsville, Alabama 35807	1	Dr. R.F. Walker USA ARRADCOM ORDAR-LCE Dover, NJ 07801	1
Mr. G.F. Mangum Thiokol Corporation Huntsville Division Huntsville, Alabama 35807	1	Dr. T. Sinden Munitions Directorate Propellants and Explosives Defence Equipment Staff British Embassy 3100 Massachusetts Ave. Washington, D.C. 20008	1
Mr. E.S. Sutton Thiokol Corporation Elkton Division P.O. Box 241 Elkton, MD 21921	1	LTC B. Loving AFROL/LK Edwards AFB, CA 93523	1
Dr. G. Thompson Thiokol Wasatch Division MS 240 P.O. Box 524 Brigham City, UT 84302	1	Professor Alan N. Gent Institute of Polymer Science University of Akron Akron, OH 44325	1
Dr. T.F. Davidson Technical Director Thiokol Corporation Government Systems Group P.O. Box 9253 Ogden, Utah 84409	1	Mr. J. M. Frankie Army Ballistic Research Labs ARRADCOM Code ORDAR-BLI Aberdeen Proving Ground, MD 21005	1

DISTRIBUTION LIST

<u>No. Copies</u>	<u>No. Copies</u>
Dr. Ingo W. May Army Ballistic Research Labs ARRADCOM Code ORDAR-BLI Aberdeen Proving Ground, MD 21005	1
Professor N.W. Tschoegl California Institute of Tech Dept. of Chemical Engineering Pasadena, CA 91125	1
Professor M.D. Nicol University of California Dept. of Chemistry 405 Hilgard Avenue Los Angeles, CA 90024	1
Professor A. G. Evans University of California Berkeley, CA 94720	1
Professor T. Litovitz Catholic Univ. of America Physics Department 520 Michigan Ave., N.E. Washington, D.C. 20017	1
Professor W. G. Knauss Graduate Aeronautical Lab California Institute of Tech. Pasadena, CA 91125	1
Professor Edward Price Georgia Institute of Tech. School of Aerospace Engin. Atlanta, Georgia 30332	1
Dr. Kenneth O. Hartman Hercules Aerospace Division Hercules Incorporated P.O. Box 210 Cumberland, MD 21502	1
Dr. Thor L. Smith IBM Research Lab 042.282 San Jose, CA 95193	1
Dr. J. P. Marshall Dept. 52-35, Bldg. 204/2 Lockheed Missile & Space Co. 3251 Hanover Street Palo Alto, CA 94304	1
Ms. Joan L. Janney Los Alamos National Lab Mail Stop 920 Los Alamos, NM 87545	1
Dr. J. M. Walsh Los Alamos Scientific Lab Los Alamos, NM 87545	1
Professor R. W. Armstrong Univ. of Maryland Department of Mechanical Eng. College Park, MD 20742	1
Prof. Richard A. Reinhardt Naval Postgraduate School Physics & Chemistry Dept. Monterey, CA 93940	1
Dr. R. Bernecker Naval Surface Weapons Center Code R13 White Oak, Silver Spring, MD 20910	1
Dr. M. J. Kamlet Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910	1
Professor J. D. Achenbach Northwestern University Dept. of Civil Engineering Evanston, IL 60201	1
Dr. N. L. Basdekas Office of Naval Research Mechanics Program, Code 432 Arlington, VA 22217	1
Professor Kenneth Kuo Pennsylvania State Univ. Dept. of Mechanical Engineering University Park, PA 16802	1

DISTRIBUTION LIST

	<u>No. Copies</u>		<u>No. Copies</u>
Dr. S. Sheffield Sandia Laboratories Division 2513 P.O. Box 5800 Albuquerque, NM 87185	1	ONR Resident Representative Ohio State University Res. Ctr. 1314 Kinnear Road Columbus, OH 43212	1
Dr. M. Farber Space Sciences, Inc. 135 Maple Avenue Monrovia, CA 91016	1		
Dr. Y. M. Gupta SRI International 333 Ravenswood Avenue Menlo Park, CA 94025	1		
Mr. M. Hill SRI International 333 Ravenswood Avenue Menlo Park, CA 94025	1		
Professor Richard A. Schapery Texas A&M Univ. Dept of Civil Engineering College Station, TX 77843	1		
Dr. Stephen Swanson Univ. of Utah Dept. of Mech. & Industrial Engineering MEB 3008 Salt Lake City, UT 84112	1		
Mr. J. D. Byrd Thiokol Corp. Huntsville Huntsville Div. Huntsville, AL 35807	1		
Professor G. D. Duvall Washington State University Dept. of Physics Pullman, WA 99163	1		
Prof. T. Dickinson Washington State University Dept. of Physics Pullman, WA 99163	1		